

Five things to know about Dark Matter

Alan Robinson

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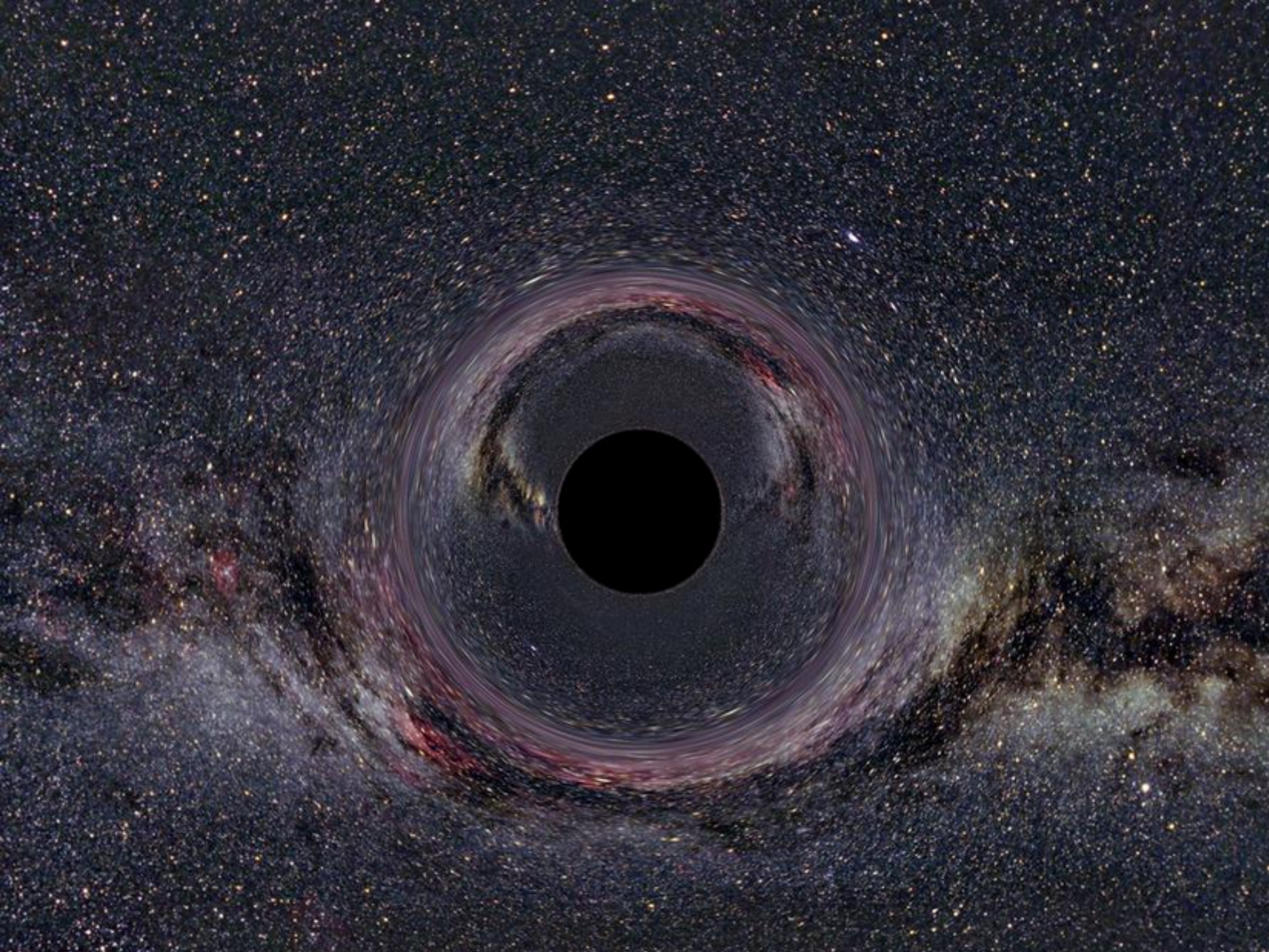
Fermilab Ask-a-Scientist

Five things to know about

Dark Matter

Dark

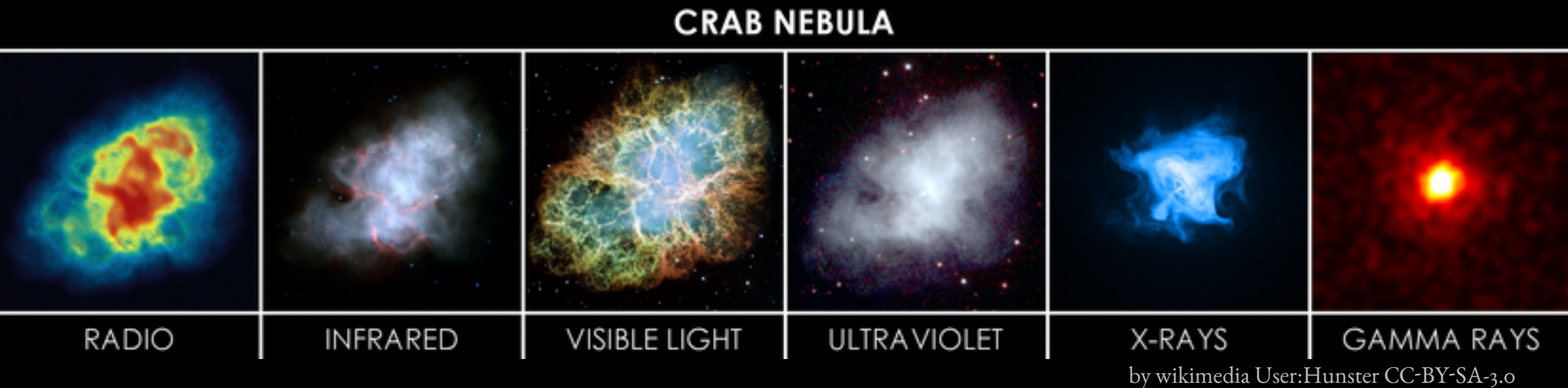
- Does not affect light



Dark

- Does not affect light
 - Does not absorb light
- ~~black~~

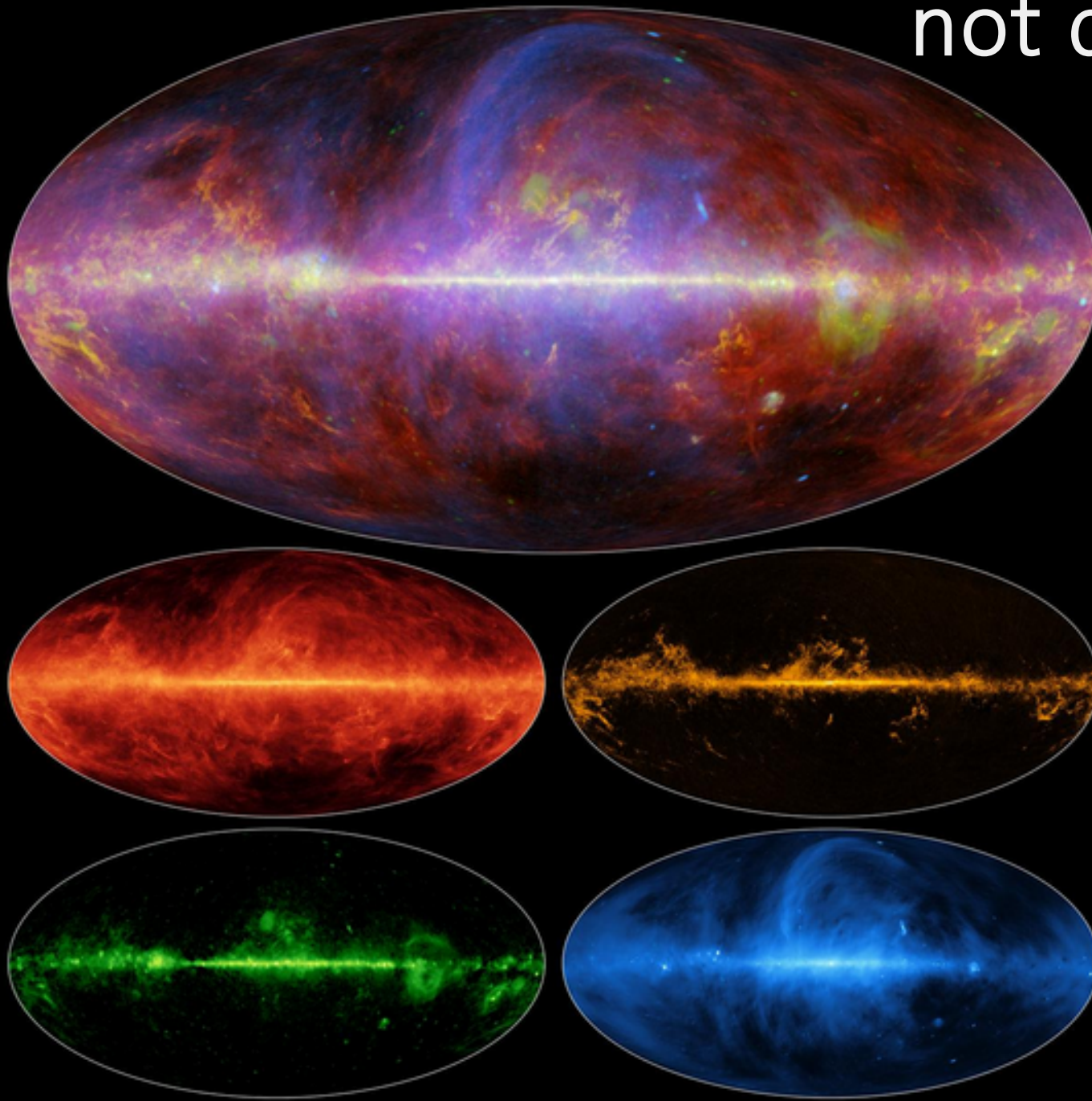
Interstellar and intergalactic dust does absorb light



The absorption changes with the wavelength of light, and depends on where you look

Dust in the Milky Way

not dark matter



Dark

- Does not affect light
 - Does not absorb light
~~black~~
 - Does not refract light
~~transparent~~

A deep-field astronomical image from the Hubble Space Telescope, showing a vast field of galaxies. The image is filled with numerous galaxies of various shapes and sizes, including spiral, elliptical, and irregular forms. The galaxies are scattered across a dark, star-filled background. Some galaxies are bright and clear, while others are faint and distant. The overall scene depicts the immense scale and diversity of galaxies in the universe.

We can see the earliest galaxies ...

The image is a deep-field photograph from the Hubble Space Telescope, showing a vast number of galaxies in a single field of view. The galaxies are of various shapes and sizes, some appearing as bright, smooth ellipses, while others are more irregular or filamentary. They are scattered across a dark, black background, with some appearing in small groups and others in isolation. The colors range from bright white and yellow to deep blues and oranges, representing different wavelengths of light captured by the telescope. The overall effect is a sense of immense scale and the diversity of cosmic structures.

We can see the earliest galaxies ...
undistorted by the Milky Way's dark matter

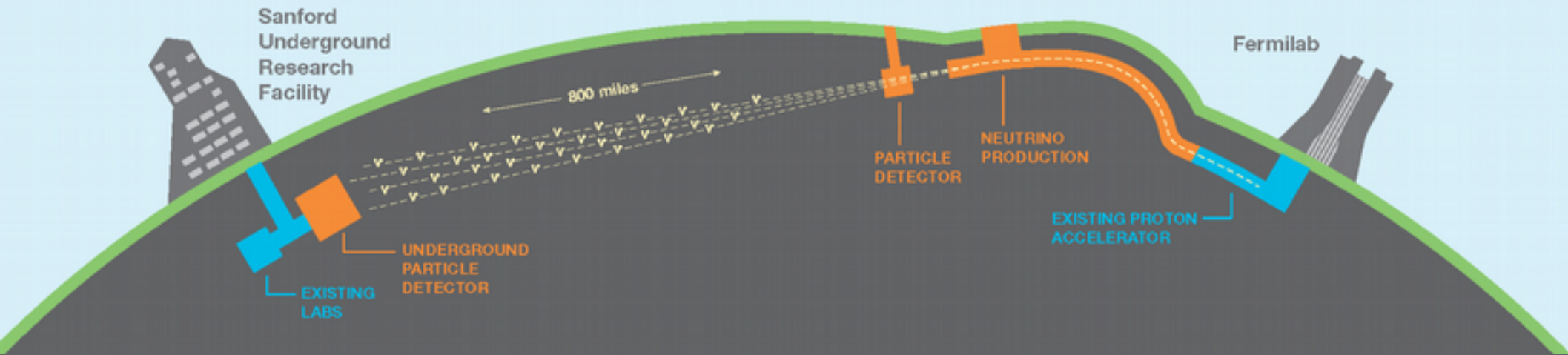
Dark

- Does not affect light
 - Does not absorb light
~~black~~
 - Does not refract light
~~transparent~~
 - Does not create light

Dark

- Does not affect light
 - Does not absorb light
~~black~~
 - Does not refract light
~~transparent~~
 - Does not create light
 - Electrically neutral

Long baseline neutrino facility

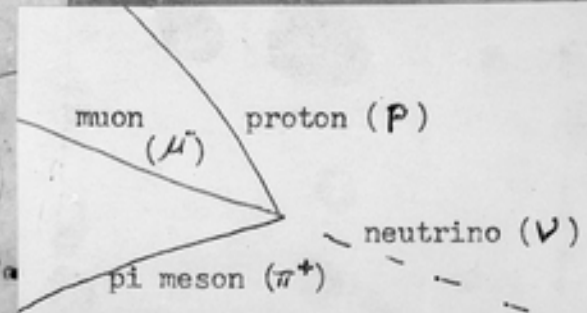



Electrically neutral particles pass through matter without stopping

Neutral particles are hard to detect

e.g. Large
detectors are
needed to see
neutrinos

Argonne 12-ft bubble chamber



A large, spherical, metallic dark matter detector is being assembled in a tunnel. The detector is made of polished metal and has a circular flange with many small bolts around its equator. A person in a blue jumpsuit and white hard hat stands next to it for scale. The tunnel walls are lined with corrugated metal. Various cables and equipment are visible in the foreground.

We're building large
dark matter
detectors

Five things to know about Dark Matter

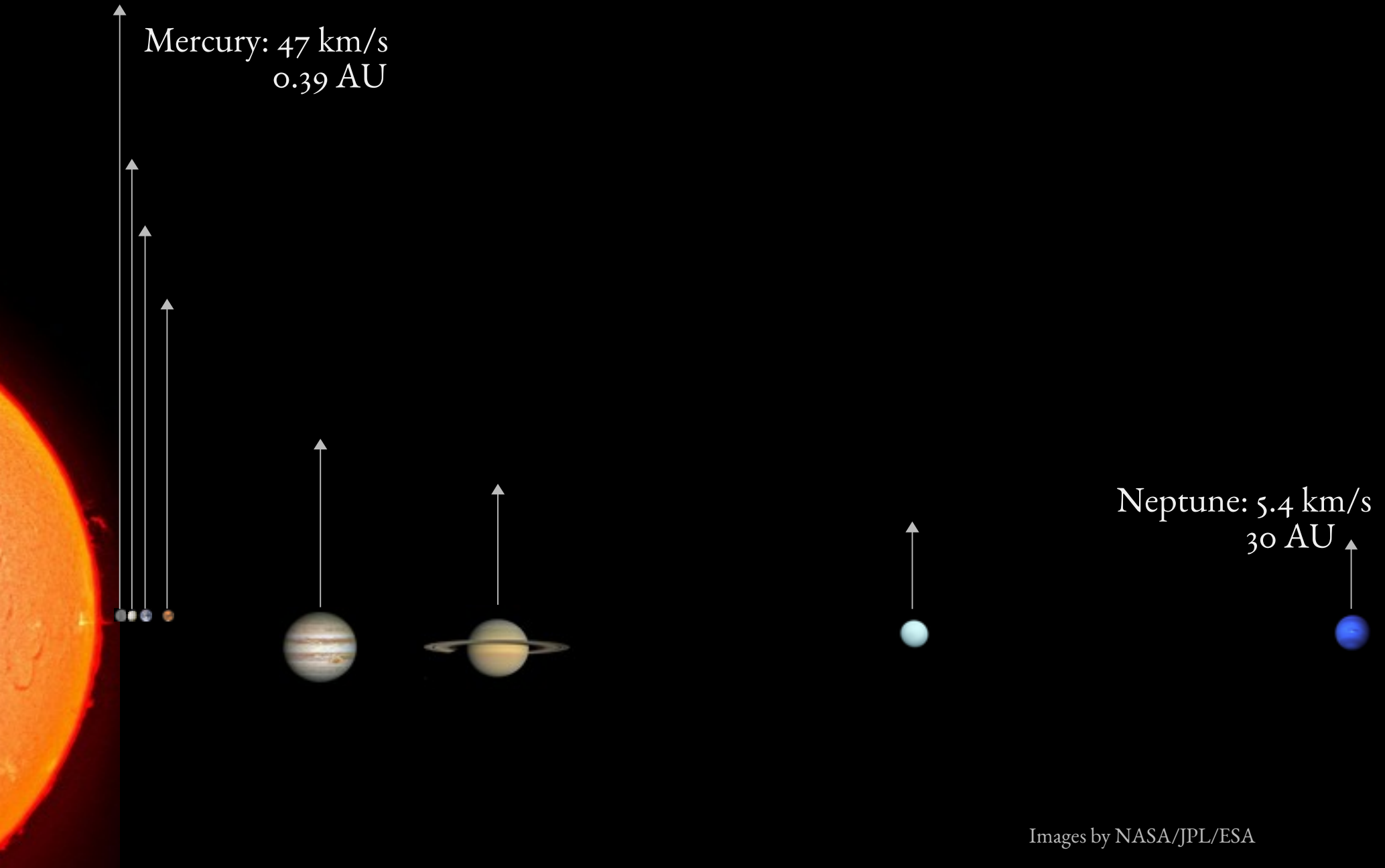
Five things to know about

Dark Matter

Matter

- Dark matter has mass

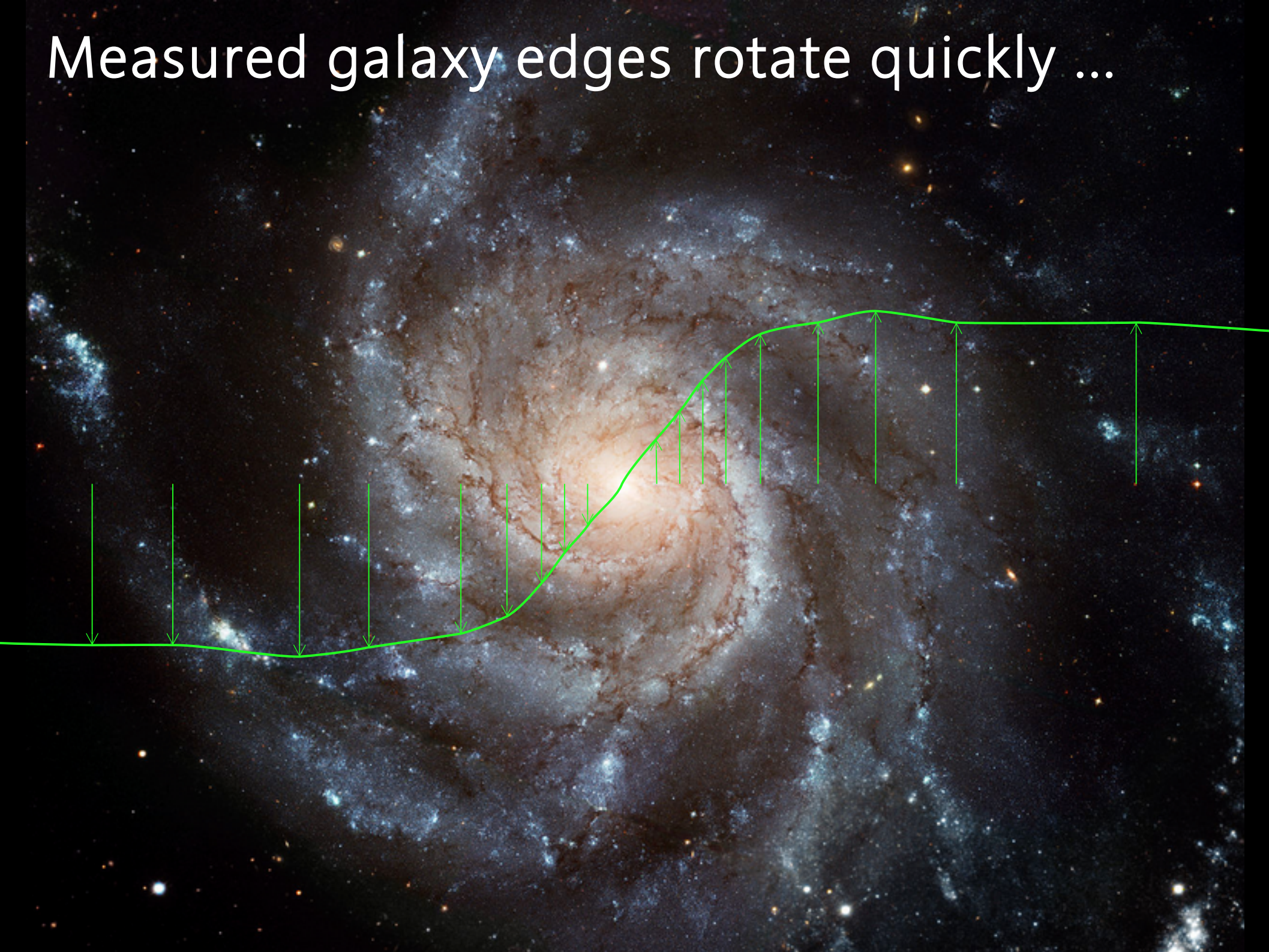
Planets revolve more slowly the farther they are from the massive sun



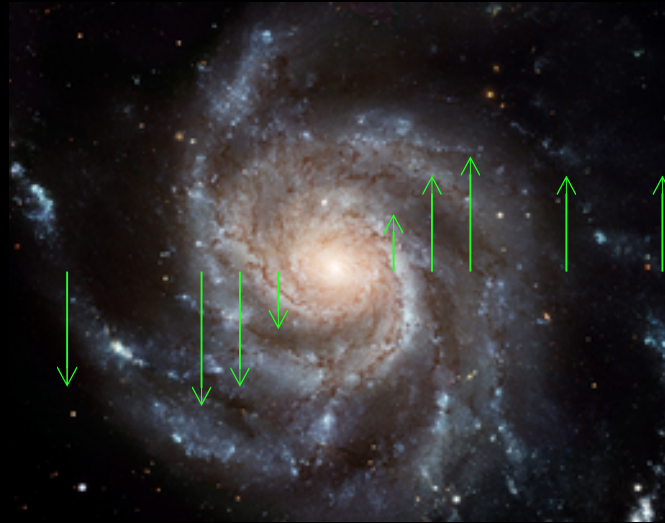
If only stars and dust made galaxies,
they would rotate like this



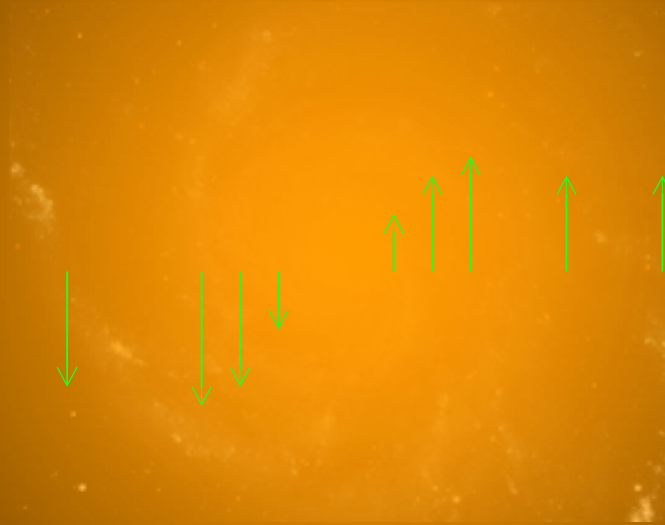
Measured galaxy edges rotate quickly ...



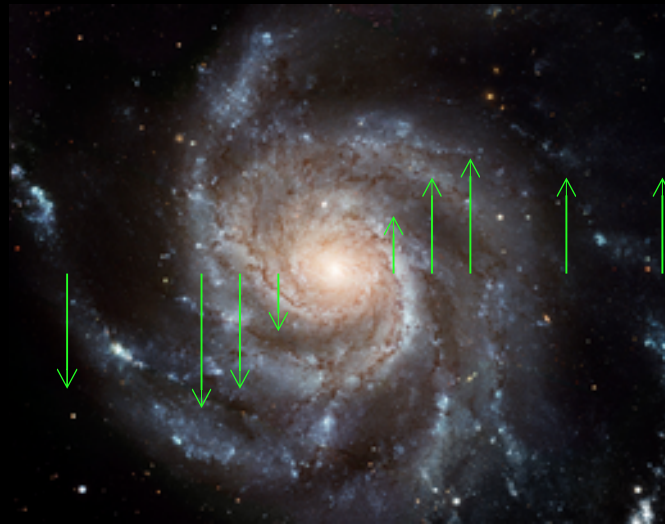
the galaxy's dark matter is much larger
than its stars in size and mass



the galaxy's dark matter is much larger
than its stars in size and mass



galactic rotation shows
the hidden dark matter



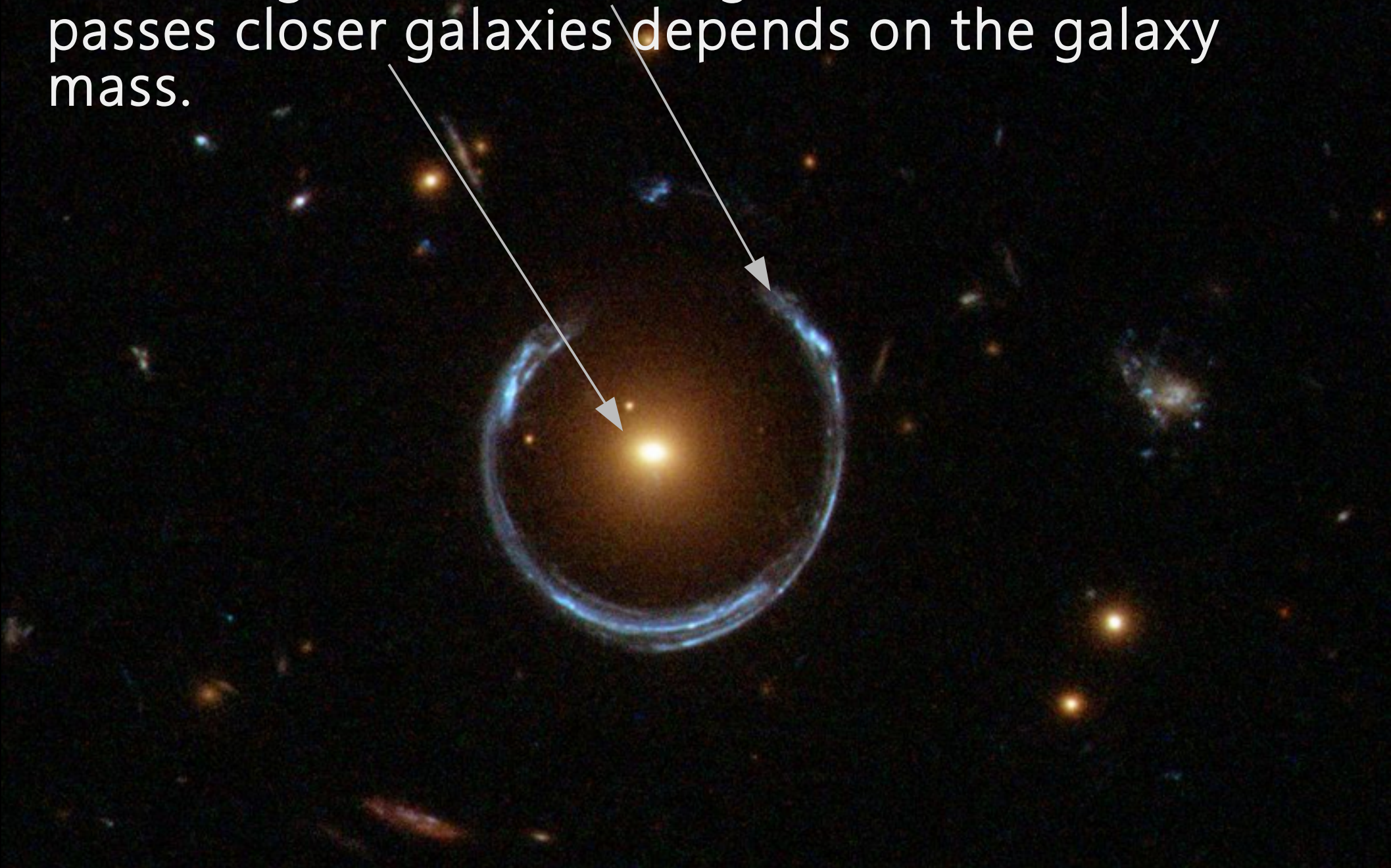
galactic rotation shows
the hidden dark matter

Matter

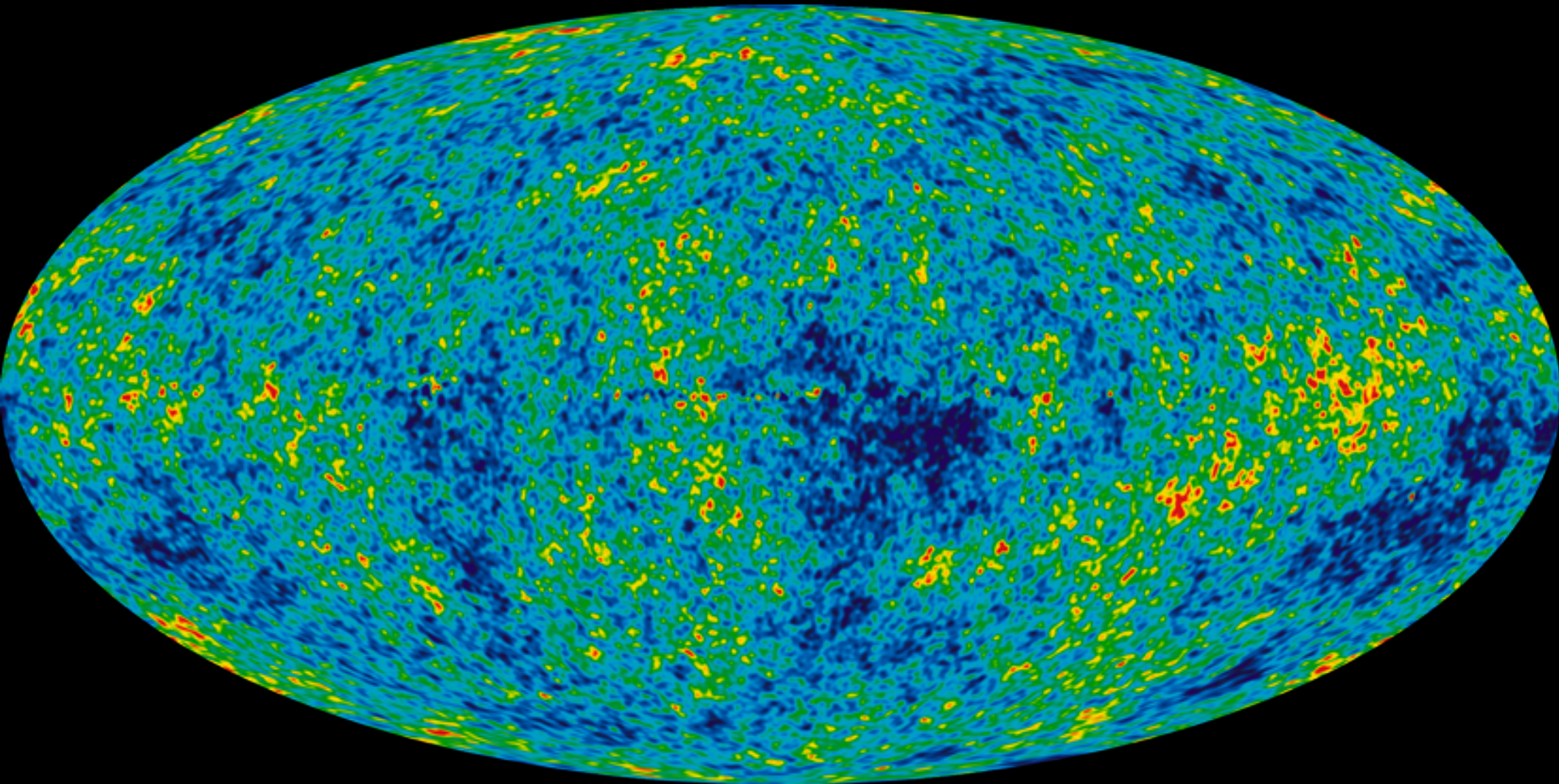
- Has mass
 - $\times 6$ more mass than visible stars and dust
 - Seen with
 - Galactic rotation
 - Gravitational lensing
 - Big Bang
- Must be radioactively stable

Gravitational Lensing

How light from distant galaxies bends as it passes closer galaxies depends on the galaxy mass.



The size and shape of ripples in the early universe depends (among other things) on how much dark matter is present



Five things to know about Dark Matter

Five things to know about

Dark Matter

Builder of galaxies

$z = 14.5$

50 Mpc/h

A cosmic map showing the distribution of matter at redshift $z = 14.5$. The map displays a dense field of dark, irregularly shaped structures against a reddish-brown background. These structures represent the early stages of galaxy formation and are distributed across the entire field of view. A scale bar in the bottom left corner indicates a distance of 50 Mpc/h.

Galaxies formed inside clumps of dense gas.

500 Mpc/h

Every dot is a galaxy today

Galaxies formed inside clumps of dense gas
where dark matter was concentrated 14
billion years ago.

500 Mpc/h



Without dark matter, our galaxy wouldn't
have formed.

Builder of Galaxies

- Galaxies were made where there was dark matter to help concentrate gas and dust.

Without dark matter, our galaxy wouldn't have formed.

Five things to know about
Dark Matter
Builder of galaxies

Five things to know about

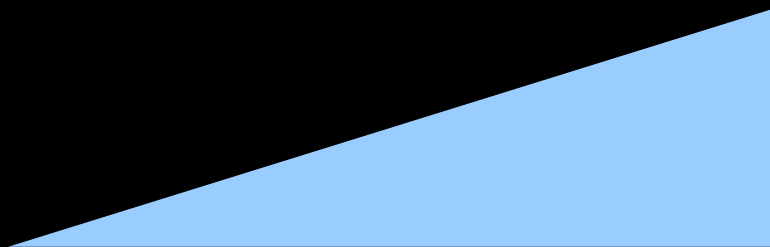
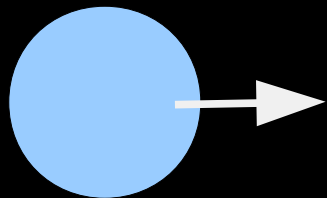
Cold Dark Matter

Builder of galaxies

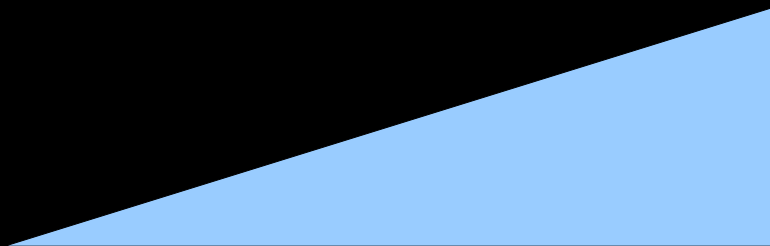
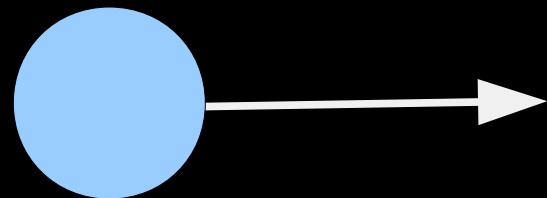
Cold

- Particles travelling slower than the speed of light

$$v < c$$



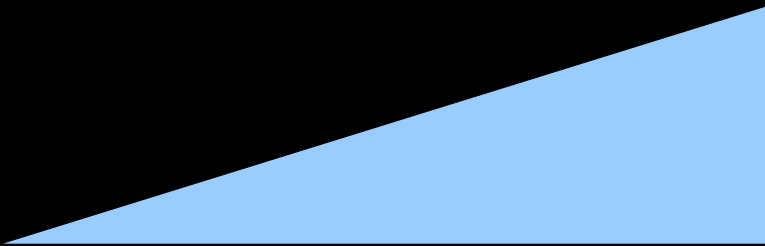
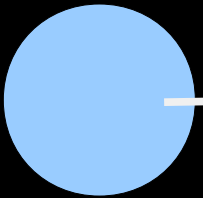
$$v \sim c$$



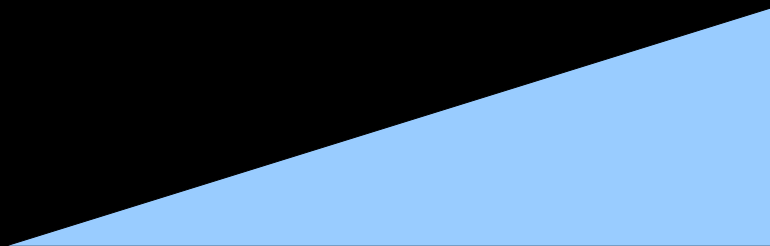
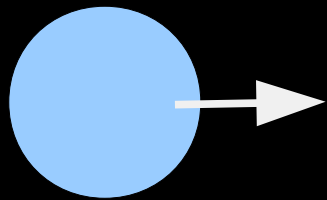
$$v < c$$



$$v \sim c$$



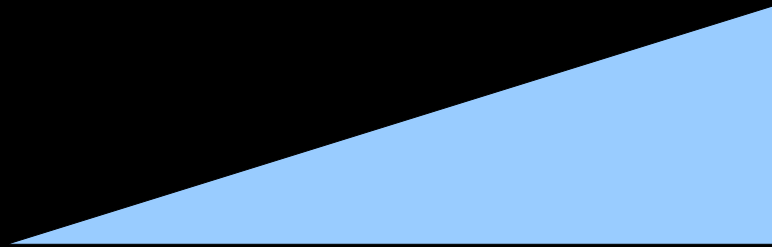
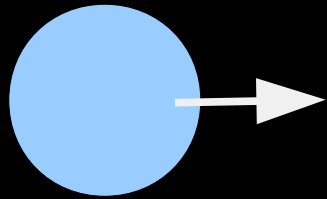
$$v < c$$



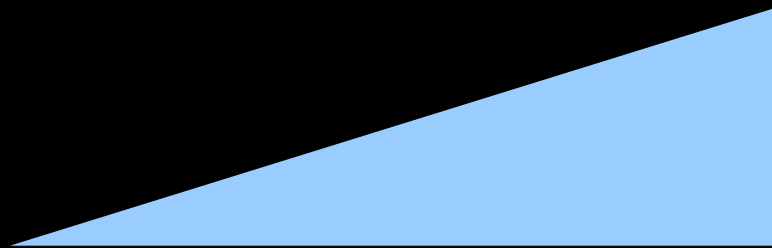
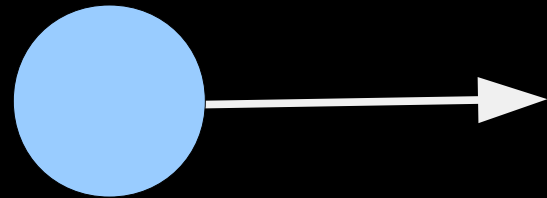
$$v \sim c$$



$v < c$ Loses velocity



$v \sim c$ Loses relativistic mass



Cold

- Particles travelling slower than the speed of light
 - Stays within galaxies
 - Matches the observed expansion of the universe.
- Must be a heavy particle in thermal models
 - keV/c^2 to TeV/c^2 mass

Five things to know about
Cold Dark Matter

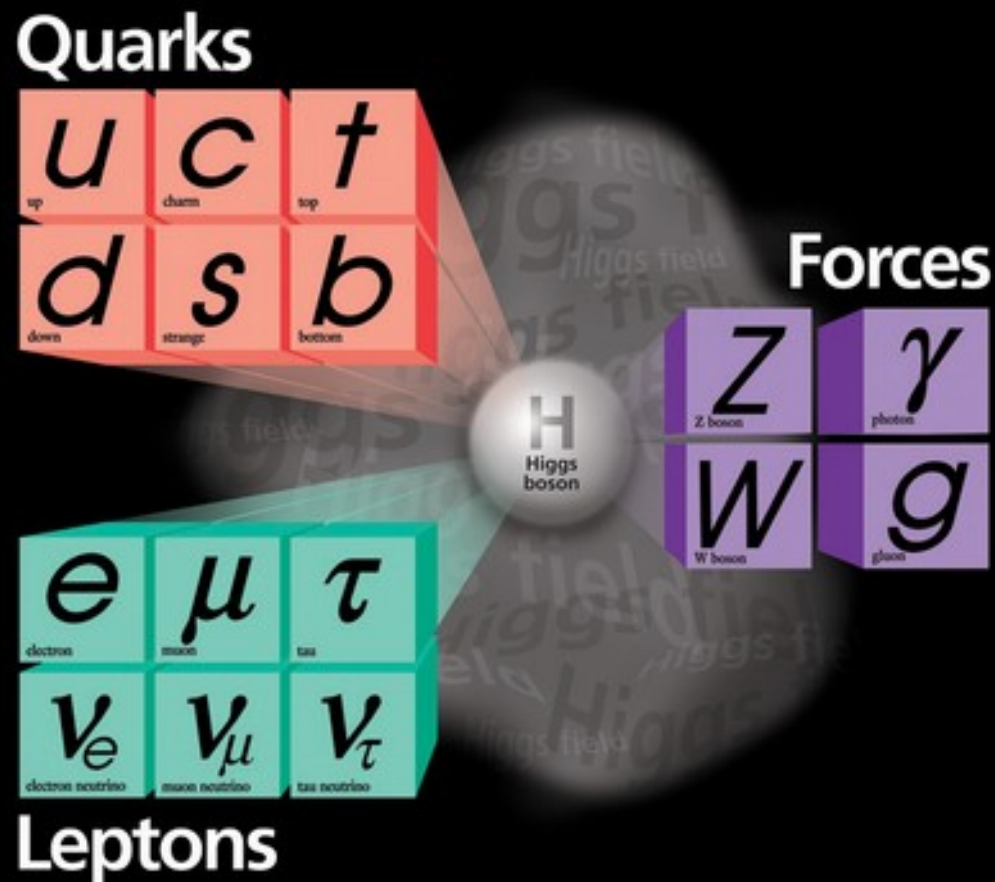
Builder of galaxies

Five things to know about
Cold Dark Matter

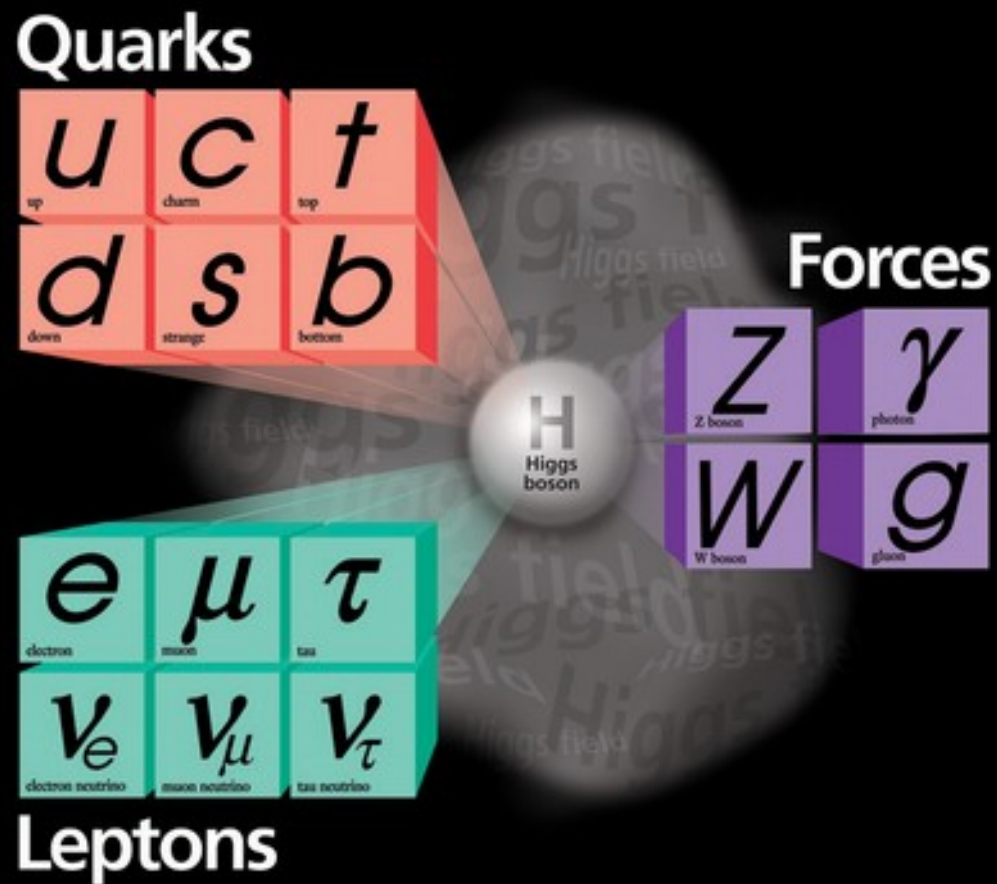
Builder of galaxies

We know
the standard model of particle physics

We know
the standard model of particle physics

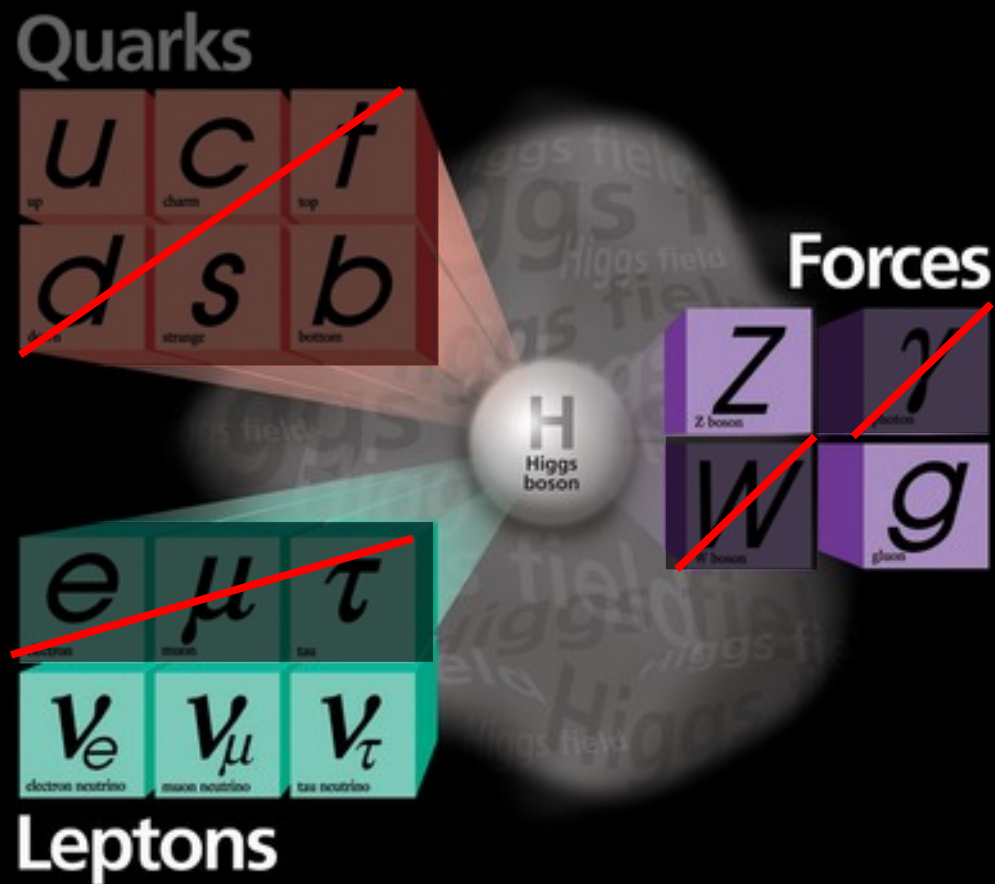


Where's dark matter?



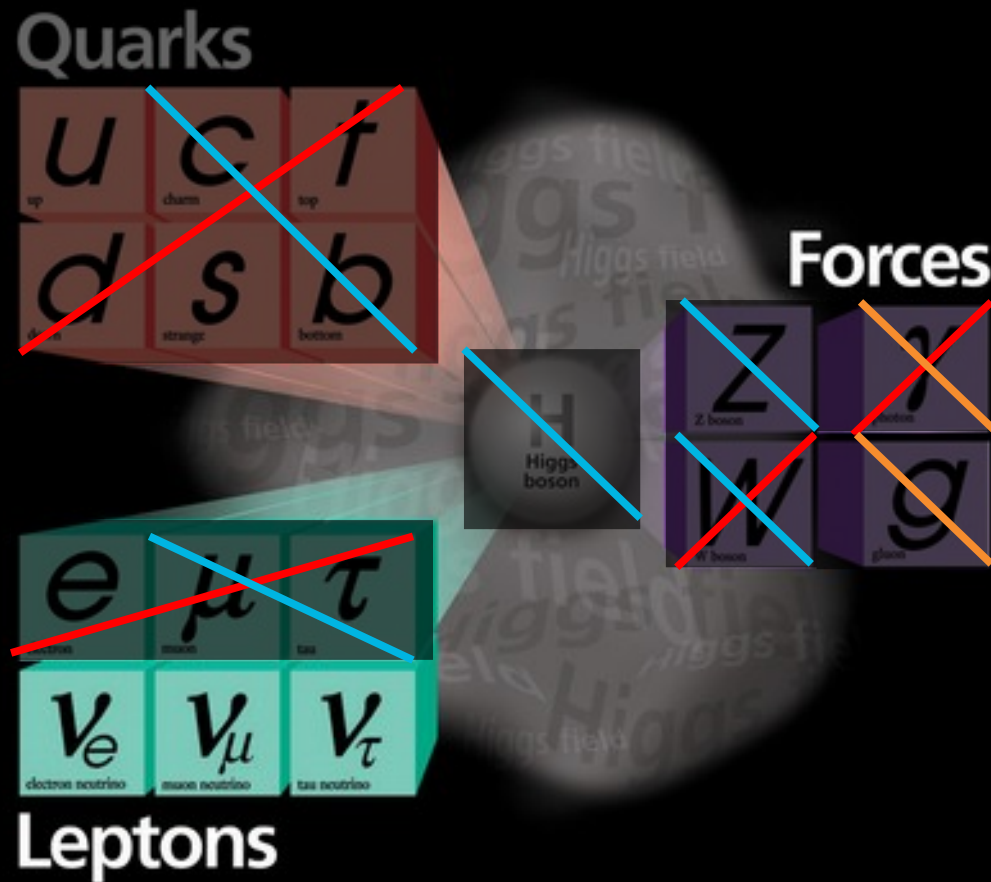
Where's dark matter?

- Dark



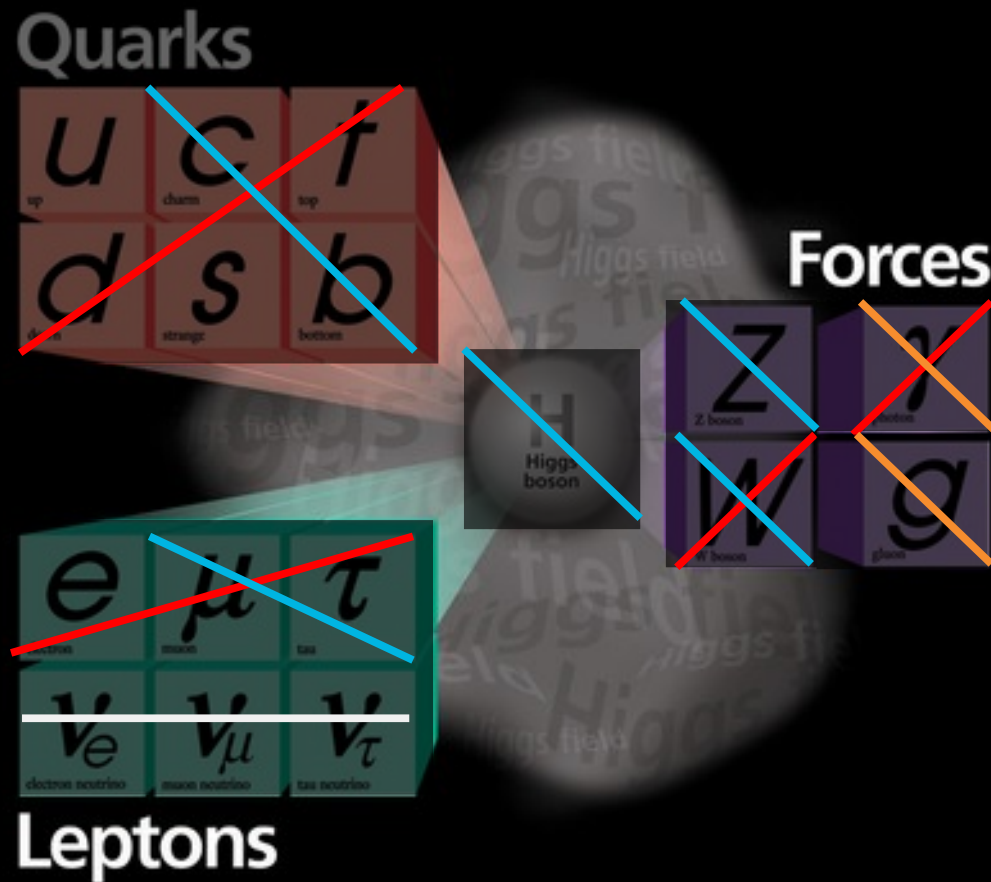
Where's dark matter?

- **Dark**
- **Massive and stable**



Where's dark matter?

- Dark
- Massive and stable
- Cold



We know
the standard model of particle physics
doesn't include dark matter.

We know
the standard model of particle physics
doesn't include dark matter.

or solutions to

- Matter/antimatter
- Strong CP problem
- Hierarchy problem

Extensions to the standard model include dark matter and solutions to

- Matter/antimatter
 - Asymmetric DM
- Strong CP problem
 - Axions
- Hierarchy problem
 - Supersymmetry

We know

Discovering dark matter interactions
is key to understanding how our
universe works.

Five things to know about Cold Dark Matter

Builder of galaxies

Discovering dark matter interactions
is key to understanding how our
universe works.